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Relative Abundance, Food Habits, Age and Growth of Northern Pike in 5 Susitna River Drainage Lakes, 2009–2012

by

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and

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Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA SERIES NO. 16-34

RELATIVE ABUNDANCE, FOOD HABITS, AGE AND GROWTH OF NORTHERN PIKE IN 5 SUSITNA RIVER DRAINAGE LAKES, 2009–2012

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Relative abundance, food habits, age, and growth of northern pike *Esox lucius*, were compared among 3 lakes known to rear juvenile salmon (Chelatna, Shell, and Whiskey) in the Susitna River watershed and 2 additional lakes where juvenile salmon have apparently been extirpated, probably by a combination of northern pike predation and beaver dams that block adult migration (Redshirt and Trapper). Mean catch per hour (CPUE) in variable-mesh gillnets was used to estimate northern pike relative abundance in each lake. Mean gillnet CPUE differed significantly ($P < 0.001$) among lakes and were lower in Chelatna and Shell lakes compared with the other 3 lakes. In lakes with salmon, northern pike diets were dominated by other fish and salmon (73%); whereas, lakes without salmon were dominated by invertebrates (91%). Diets without salmon and other fish indicated that all fish had been largely extirpated. Northern pike in Trapper Lake exhibited the highest rate of cannibalism. The number of juvenile salmon found in northern pike stomachs differed ($P < 0.001$) among six 10-cm northern pike length classes. Northern pike <50 cm in length consumed 75% of the juvenile salmon. Prey length distributions differed ($P < 0.001$) between salmon and other fish prey. All salmon prey were <15 cm in length, whereas 65% of other fish prey were >15 cm in length. In lakes without salmon, age compositions were skewed toward younger fish and lifespan appeared to be reduced. Male proportions generally declined with age but these patterns did not differ among lakes. Growth was significantly ($P < 0.05$) negatively density dependent and growth was higher in Chelatna and Shell lakes. High densities and the high incidence of invertebrates in northern pike diets probably contributed to lower growth rates in Redshirt and Trapper lakes because growth rates are typically higher among piscivores.

Key words: northern pike, *Esox Lucius*, catch per unit effort CPUE, relative abundance, invasive species, salmon smolt, stomach contents, Susitna, Susitna River, Chelatna Lake, Shell Lake, Whiskey Lake, Redshirt Lake, Trapper Lake.

INTRODUCTION

During the spring and summer from 2009 to 2012, the Alaska Department of Fish and Game (ADF&G) and Cook Inlet Aquaculture Association (CIAA) conducted northern pike *Esox lucius* surveys on lakes within the Susitna River drainage to ascertain their relative abundance, age composition, size, food habits and their consumption of migrating salmonid smolt, in particular, juvenile sockeye salmon *Oncorhynchus nerka* (Figure 1).

Originating in the Alaska Range, the Susitna River watershed encompasses 49,210 km^2 and flows southwesterly for approximately 400 km where it empties into the Cook Inlet west of Anchorage. Historically, the Susitna River drainage, including 3 major tributaries, Yentna, Chulitna, and Talkeetna rivers, contains numerous sockeye salmon nursery lakes and sloughs (Tarbox and Kyle 1989; Thompson et al 1986).

Habitats within this watershed also support large beds of aquatic vegetation conducive to spawning and rearing of northern pike, (Rutz 1996; Inskip 1982). These shallow, weedy water ways are habitats in which some juvenile salmon also rear. Northern pike are indigenous north and west of the Alaska Range, but not in Southcentral Alaska, including the Susitna River drainage (Massengill 2011). Whitmore et al. (1994) confirmed that northern pike have spread throughout much of the Susitna drainage because they were illegally introduced into the system during the 1950s. Rutz (1996) indicated that northern pike prey on juvenile salmon where these species co-occur in the Susitna drainage. Illegal introduction and spread of northern pike into the lakes and streams of the Susitna Valley has become a threat to the sport and commercial fisheries of the Upper Cook Inlet area. Many of the lakes that historically produced salmon in the Susitna drainage now have northern pike populations (Rutz 1996). Some resident fish species directly affected by northern pike predation are rainbow trout *O. mykiss*, lake trout *Salvelinus namaycush*, Dolly Varden *Salvelinus malma*, Arctic grayling *Thymallus arcticus* and black fish *Dallia pectoralis*. Salmonids such as coho salmon *O. kisutch* are more strongly affected because they often share the same habitats as northern pike. Even though Chinook salmon *O. tshawytscha* and sockeye salmon are partially segregated by habitat differences (fast water or deep water), they are still affected by northern pike predation.

Studies on stocked and wild salmonids have shown that northern pike can consume from 30% to 70% of juveniles during downstream migrations (Pervozvanskiy et al. 1988; Movchan and Chechenkov 1979; Larsson 1985; Smirnov et al. 1977). Muhlfeld et al. (2008) found that introduced northern pike contribute to the decline in native salmonid populations.

Northern pike have instinctive feeding behaviors favoring soft-rayed fish species or prey of a particular size and type over other food items (Eklov and Hamrin 1989; Hoogland et al. 1956; Beyerle and Williams 1977). Eddy and Surber (1947) determined that when preferred food items were not present, northern pike became opportunistic feeders switching to what was available. Some northern pike stomachs examined by Rutz (1996) contained only invertebrates, indicating that this has occurred in some Susitna lake systems. Humpback whitefish *Coregonus pidschian*, round whitefish *Prosopium cylindraceum*, longnose sucker *Catostomus catostomus*, burbot *Lota lota*, and threespine stickleback *Gasterosteus cognatu*s are additional fish species in the Susitna River drainage affected by northern pike predation.

Since 2005, comprehensive studies conducted by ADF&G and CIAA have examined sockeye salmon production by comparing results from fall juvenile acoustic surveys, trawl surveys, limnological studies, and smolt and escapement enumeration projects. Possibly due to the spread of invasive northern pike, these studies suggested that sockeye salmon production may be in decline among the smaller lakes of the Susitna River watershed. To further investigate sockeye salmon production within the Susitna River drainage, the Alaska Sustainable Salmon Fund (AKSSF) funded ADF&G and CIAA to conduct the *Susitna Sockeye Salmon Production* project (AKSSF Project 45918). Estimates of sockeye production among all lakes studied in this project will be used to evaluate escapement goals and potential management actions. Examining consumption of juvenile salmon by northern pike may provide an understanding of how predation limits sockeye salmon production. Differences in sockeye salmon production among Susitna watershed lakes in relation to the presence or absence of northern pike may be used to evaluate potential management actions directed at controlling this invasive species.

This report describes a component of the *Susitna Sockeye Salmon Production* project, which estimated the relative abundance, size, and age composition of northern pike, and their food habits, in particular, their consumption of juvenile salmon during the smolt migration. Northern pike were sampled in 3 Susitna River drainage lakes also rearing salmonids, i.e., Chelatna, Shell, and Whiskey lakes. For comparison, northern pike were also sampled in Redshirt and Trapper lakes, where juvenile salmon were apparently extirpated by northern pike predation.

OBJECTIVES

The goal of this project was to compare northern pike relative abundance, food habits, size-age composition, and growth between 2 Susitna watershed lakes without juvenile salmon (Redshirt and Trapper) and 3 lakes with juvenile salmon (Chelatna, Shell and Whiskey) during the spring salmon smolt migration. Specific objectives were the following:

1. test for differences in the relative abundance of northern pike between lakes with and without salmon;
2. estimate northern pike diet composition in each lake and compare diets between lakes with and without salmon;

3. test for differences in number of juvenile salmon consumed among different length classes of northern pike;
4. test whether the relationship between northern pike length and fish prey lengths differed between lakes with and without salmon, and test whether prey-predator length ratios differed between salmon and non-salmon prey; and
5. test for differences in northern pike age composition, sex ratio and growth rate between lakes with and without salmon.

METHODS

SAMPLING AND DATA COLLECTION

Sockeye salmon smolt abundance was estimated by CIAA using modified fyke nets operated near the outlets of Shell and Whiskey lakes, whereas a modified Peterson estimator was used to estimate smolt populations emigrating from Chelatna Lake, including the use of standard dye-marking techniques (CIAA 2013; Shaw 2014; Ka'aihue and Weber 2015). Smolt abundance was not estimated at Redshirt and Trapper lakes because no adult spawners were identified passing through adult salmon weirs in 2009.

CIAA smolt project crews sampled northern pike for this study at Shell, Whiskey, and Chelatna lakes. Rutz (1996) observed that a majority of northern pike move to lake outlet areas or lake tributary streams subsequent to spring spawning, at which time their metabolism and foraging increases (Johnson 1966). Sampling for northern pike began as soon as possible following deployment of smolt traps and ice-free conditions because this is a period of peak northern pike activity followed by more sedentary behavior in summer (Neumann and Willis 1995; Muhlfeld et al. 2008). Sampling was divided into 3 separate events coinciding with the beginning, middle, and end of smolt emigrations. Sampling was conducted at Redshirt Lake in the summer of 2009 at the outlet and during the spring of 2011 at the upper end of the lake. Sampling was conducted near the outlets of Trapper and Whiskey lakes in the spring of 2011 and 2012, respectively. Sampling was conducted at Chelatna and Shell lakes in the spring of 2010 to 2012.

Northern pike were captured using variable-mesh gillnets near lake outlets where smolt populations were expected to emigrate. Up to 6 nets were deployed at 6 different set sites per lake near locations that offered optimal northern pike habitat (weeds, etc.) during each sampling event. In general, nets were set in the afternoon or evening and retrieved the next morning. Time of each net set and retrieval was recorded to the nearest minute. Nets (3 each) were 22.9 m long and 38.1 m long per lake. Gillnet mesh sizes were chosen to increase the size range and catchability of northern pike. Each net was 1.8 m deep and constructed of 5 panels using mesh sizes 2.5 cm, 3.8 cm, 5.1 cm, 6.4 cm, and 7.6 cm. The top line was a floating core line and the bottom line was lead weighted to sink.

Nets were set near shore in water depths ranging between 1 m and 3 m; in general nets were set perpendicular to shoreline. One end of the net was anchored to shore or to a stake, and the off shore end was "free" even though extra lead weight was added to the lead line. Nets were retrieved 1 at a time and samples processed before retrieving other nets to prevent mixing fish from different net sets. Species other than northern pike were removed in the water and released immediately.

Additional methods of catching northern pike were used to increase overall sample size and to increase the potential range of fish sizes. Hoop nets with 0.8 m opening diameters and 4.6 m wing leads were used in 2010 and baited with herring. Hoop nets were set overnight in shallow weedy areas in close proximity to variable-mesh gillnets. Hook and line methods involved the use of conventional spin casting rod and reel or set lines with attached hooks. A variety of artificial lures or herring baited hooks were used at the discretion of the field crew depending upon the time of day and what worked best.

RELATIVE ABUNDANCE

Northern pike relative abundance was estimated using catch per unit effort by hour (CPUE) in variable-mesh gillnets (Paukert and Willis 2003; Begich and McKinley 2005; Thompson 2002). First, a Kolmogorov–Smirnov test was conducted to test whether the natural-logarithm transformed CPUE data were normally distributed. Then an analysis of variance (main effects model) was conducted to test for differences in mean northern pike CPUE (natural logarithm transformed) among lakes, i.e., Log(CPUE)=LAKE. Least-squares mean CPUE were estimated for each lake and paired comparison tests were conducted. Least-squares mean CPUE for each lake were later used to test for density-dependent growth as described below. A second analysis of variance was conducted to test for differences in mean northern pike CPUE (natural-logarithm transformed) between lakes with and without salmon. In this model, lakes were nested within treatment (TRMT) groups (lakes with salmon and without salmon), i.e., Log(CPUE)=TRMT LAKE(TRMT). Least-squares mean CPUE were estimated for each treatment group. Only data from Chelatna, Redshirt, Shell, and Trapper lakes in 2011 and Whiskey Lake in 2012 were included in analyses of variance.

FOOD HABITS

Because Susitna River northern pike are an invasive species, all captured northern pike were sacrificed and their stomachs excised in the field. All prey items were identified to the lowest possible taxonomic level in the field, and fork lengths of all intact fish prey were measured to the nearest mm. If highly digested prey could not be identified, they were recorded as unidentified prey, and stomachs containing no prey were recorded as empty. Northern pike diet composition was described by the frequency of occurrence of each identified prey item in all non-empty stomachs examined at each lake (Hyslop 1980).

Two Fisher exact tests were conducted to test whether northern pike diet composition (frequency of occurrence of preys in stomachs) differed among lakes and between lakes with and without salmon. Prey items were grouped as salmon, other fish, invertebrates, and vertebrates.

A frequency distribution was constructed to examine the relationship between the number of salmonids consumed by northern pike and predator length to data from all lakes combined. A chi-square test was conducted to test whether the number of juvenile salmon found in northern pike stomachs differed among six 10-cm northern pike length classes. Only data from Chelatna, Shell, and Whiskey lakes were used in this analysis because no juvenile salmon were found in northern pike stomachs examined at Red Shirt and Trapper lakes. Two Fisher exact tests were conducted to test whether prey length distributions and prey-predator length ratios differed for salmon versus non-salmon prey. An analysis of covariance was conducted to test whether the relationship between lengths of prey fish and lengths of northern pike predators differed between lakes with and without salmon, i.e., Prey Length=Pike Length TRMT.

AGE, SEX AND GROWTH

Northern pike were sampled for sex, age, weight and length during each sampling event. Fork length (FL: length from tip of nose to fork of tail) was measured to the nearest mm and weight to the nearest 0.01 kg using a handheld scale. Sex was determined by internal examination of the body cavity for the presence of gonads or ovaries. Scales were taken from each fish to later determine age in the laboratory (Laine et al. 1991). Scales were taken from the preferred area above the pelvic fins near the lateral line and mounted directly on to a gummed card (Williams 1955). Cards were then used to make scale impressions on 0.51 mm acetate sheets using a PHI® press and viewed using a microfiche reader. Ages were determined using established criteria, and growth beyond the last annulus was considered to be plus growth (Casselman 1967; Williams 1955). Mean northern pike lengths and standard errors were calculated for each sampling period, lake, or age class. Age composition was estimated from the number of fish in each age class divided by the total number sampled.

Two Fisher exact tests were conducted to test whether northern pike age compositions differed among lakes and between lakes with and without salmon. Two chi-square tests were conducted to test whether numbers of male and female northern pike differed among lakes and between lakes with and without salmon. A logistic regression analysis was conducted to test whether proportions of male northern pike were related to age and lake. The independent class variables in the analysis were lake, age and their interaction, i.e., MALE=AGE LAKE AGE*LAKE. A backward selection procedure was used to identify the most parsimonious model. The *c*-statistic was used to evaluate model fit.

Growth of northern pike was described by fitting von Bertalanffy's growth model (Ricker 1975) to length at age data from each lake, i.e.,

$$L_t = L_\infty \left(1 - exp\left(-K(t - t_0)\right)\right),$$

where L_t was length at time (t), L_∞ was the asymptotic length of the growth curve and K was the growth coefficient describing increase in body size. We also calculated w (i.e., L_∞ x K), which Gallucci and Quinn (1979) recommended for comparisons due to the interdependence of the von Bertalanffy model parameters. Growth parameters were estimated for male and female northern pike and both sexes pooled. Nine linear regression analyses were then conducted using L_∞, K, and w as dependent variables and mean northern pike gillnet CPUE from each lake as independent variables. The regressions were weighted by the sample size available for estimating growth parameters in each lake. Regression analyses were conducted using growth parameters for male and female northern pike and both sexes pooled.

RESULTS AND DISCUSSION

RELATIVE ABUNDANCE

A total of 765 northern pike were captured from 2009 to 2012 through 1,849 hours of fishing effort (Table 1). Mean gillnet CPUE ranged from 0.342 to 1.029 northern pike per hour of effort. Among the lakes sampled, Shell Lake produced 205 northern pike during a total of 610 hours of gillnet fishing for the lowest overall gillnet CPUE of 0.342. The highest gillnet CPUE (1.029) was at Whiskey Lake, where 122 northern pike were caught during 114 hours of gillnet fishing.

Gillnet CPUE from Chelatna Lake ranged from 0.212 in 2011 to 0.524 in 2010 (Table 2). In 2010, hoop nets were fished in Chelatna Lake for approximately 72 hours, and 0 northern pike were captured. It was not determined if poor hoop net performance resulted from net placement or seasonal timing due to northern pike movements. Consequently hoop nets were not fished in 2011 and 2012. Variable-mesh gillnets were the predominant method utilized for catching northern pike. CPUE data (2010–2012) for hook and line indicated this gear was more successful in catching fish than variable-mesh gillnets, but this method did not utilize the field crew's time as efficiently. Northern pike catch rates between early, mid, and late smolt migration periods indicated no consistent pattern from 2010 to 2012. Because Chelatna Lake is glacial in nature and has relatively few weedy shallow areas, the low CPUE may be the result of having limited shoreline habitat suitable for northern pike (Rutz 1996).

Overall, gillnet CPUE were the lowest at Shell Lake, ranging from 0.309 in 2011 to 0.439 in 2012 with an overall mean CPUE of 0.342 (Table 3). Hook and line efforts produced the highest CPUE; however, it was more convenient to use gillnets. There was no consistent pattern in northern pike catch rates among early, mid, or late smolt migration periods. Gillnet CPUE declined during the season in 2010 and 2011 but increased seasonally in 2012.

Redshirt and Trapper lakes produced mid-range gillnet CPUE among the 5 lakes sampled, with mean CPUE of 0.596 at Trapper Lake and 0.634 at Redshirt Lake (Table 4). Whiskey Lake's deepest area is 8 meters, but the majority of the lake ranges in depths from 1 to 3 meters and has significant vegetation growth conducive to rearing northern pike. Consistent with its availability of suitable habitat and fish prey, Whiskey Lake's gillnet CPUE was the highest of the 5 lakes at 1.029. An additional 54 northern pike were captured in smolt traps as they attempted to migrate between spawning areas. Diana (1979) determined that metabolic and digestion rates increased in northern pike as water temperature increased. It is not known if shallower and warmer waters in Whiskey Lake affected northern pike activity and catch rates.

The highest incidental non-northern pike catch for all lakes was the longnose sucker *Catostomus catostomus* (Table 5). Longnose sucker were commonly observed spawning in shallows and near lake outlets early in the spring. Other incidental catches in Chelatna Lake consisted of rainbow trout, round whitefish, and grayling. The majority of the rainbow trout and round whitefish were caught during the early smolt migration period just as ice was going out. Excluding longnose sucker, Shell Lake produced minimal bycatch except for 10 lake trout in 2011 (Table 5). Incidental catches from Redshirt and Trapper lakes included longnose sucker and humpback whitefish. Whiskey Lake's non-northern pike incidental catches were minimal.

A Kolmogorov–Smirnov test indicated that the distribution of natural-logarithm transformed gillnet CPUE data was not significantly different ($P > 0.150$) from a normal distribution. Analysis of variance indicated that mean gillnet CPUE differed significantly ($P < 0.001$) among lakes (Figure 2a). Paired comparison tests indicated that mean gillnet CPUE were significantly ($P < =0.05$) lower at Chelatna and Shell lakes compared to Redshirt, Trapper, and Whiskey lakes, and gillnet CPUE did not differ among Redshirt, Trapper, and Whiskey lakes.

A second analysis of variance indicated that natural-logarithm transformed mean CPUE was significantly ($P < 0.001$) lower in lakes without salmon than in lakes with salmon (Figure 2b). This result seemed counter intuitive because mean CPUE in Whiskey Lake was higher than in Chelatna and Shell lakes. A further examination of the distribution of the untransformed CPUE indicated that CPUE in Chelatna and Shell lakes were skewed toward lower values, CPUE in Whiskey Lake were bimodally distributed, and CPUE in Redshirt and Trapper lakes were more unimodal (Figure 3a). Overall, the distributions of CPUE in lakes with salmon were strongly skewed toward lower values and few high values suggesting a more patchy distribution (Figure 3b). Conversely, CPUE in lakes without salmon were more unimodal suggesting a more uniform distribution.

FOOD HABITS

A total of 741 northern pike stomachs were examined from 5 Susitna River drainage lakes. Overall, 67% were not empty and 33% were empty (Table 6). These findings were consistent with results from 4 other Susitna River tributaries (Hewitt, Indian, Moose, and Whitsoe), where 64% of northern pike stomachs were not empty and 36% were empty (Rutz 1999). Redshirt and Trapper lakes had the highest percentage of non-empty stomachs (Table 6): Redshirt Lake (88%), Trapper Lake (78%), Chelatna, Whiskey and Shell lakes (61–63%).

Of all non-empty stomachs examined, 23% contained salmonids including rainbow trout (Table 6). Salmonids were only found in northern pike sampled in Chelatna, Shell, and Whiskey lakes. Northern pike in Chelatna Lake exhibited the highest incidence of sockeye salmon in stomachs (22%), followed by Whiskey Lake (8%) and Shell Lake (6%). Salmonid predation in Shell Lake decreased from 2010 to 2012 congruent with decreasing smolt emigration counts (Weber 2013; Ka'aihue and Weber 2015). Sockeye salmon found in northern pike stomachs averaged 46 mm in length in Chelatna, 123 mm in Shell Lake, and 67 mm in Whiskey Lake (Table 7). At Chelatna Lake, nearly equal numbers of male and female northern pike consumed salmonids; whereas at Shell and Whiskey lakes about twice as many male than female northern pike consumed salmonids, although sample sizes were small (Table 8). Most of the northern pike that consumed salmonids were less than 500 mm in Chelatna and Whiskey lakes but larger than 500 mm in Shell Lake (Table 8).

Other fish (sculpin, suckers, and unidentifiable fish) comprised 31% of prey found in non-empty stomachs at Chelatna Lake. Other fish in stomachs from Shell and Whiskey lakes were unidentifiable but consisted of flesh masses permeated with stickleback spines. Identifiable sticklebacks were found in 28% of Shell Lake non-empty stomachs and 61% of Whiskey Lake non-empty stomachs (Table 6). Northern pike prefer salmonids over sticklebacks and a high incidence of sticklebacks in northern pike stomachs at Shell and Whiskey lakes suggests that salmonids were not abundant or that prey selection was affected by high northern pike densities (Rutz 1999). Sepulveda et al. (2013) also found that northern pike consumed alternative prey (primarily Arctic lamprey *Lampetra camtschatica* and slimy sculpin *Cottus cognatus*) when salmonids were less abundant. Cannibalism among northern pike occurred in all 5 lakes to a small degree but was highest (29%) at Trapper Lake, where the mean length of cannibalized northern pike was 206 mm (Table 7).

Invertebrates were found in 230 (47%) of non-empty northern pike stomachs from all lakes (Table 6). All non-empty stomachs from Redshirt Lake contained invertebrates. Redshirt Lake was the only lake where northern pike ingested amphipods in large quantities (Table 6). Insects and leeches dominated the invertebrate prey in all lakes, but at Redshirt and Trapper lakes they were the primary food items.

In lakes without salmon, lack of other fish in northern pike diets indicated that all fish had been largely extirpated from these lakes. Two Fisher exact tests indicated that northern pike diet compositions were significantly different (χ^2 = 329.9, df = 12, P < 0.001) among lakes and significantly different (χ^2 = 217.8, df = 3, P < 0.001) between lakes with and without salmon (Figure 4). In lakes with salmon, northern pike diets were dominated by other fish and salmon

(73%); whereas, in lakes without salmon, their diets were dominated by invertebrates (91%). Because northern pike prefer soft-rayed fish over invertebrates (Hoogland et al. 1956; Beyerle and Williams 1977; Eklov and Hamrin 1989), lack of fish in northern pike stomachs at Redshirt and Trapper lakes indicates that these preys were probably not available (Diana et al. 1977; Rutz 1999).

When data were pooled across all lakes, most juvenile salmon were consumed by relatively small northern pike and salmon preys were relatively small compared to the northern pike that consumed them. A chi-square test indicated that the number of juvenile salmon found in northern pike stomachs differed (χ^2 = 55.6, df = 5, P < 0.001) among six 10-cm northern pike length classes (Figure 5). Northern pike less than 500 mm in length consumed 75% of the juvenile salmon. Thus, our results were generally consistent with those of Sepulveda et al. (2013), who found that smaller northern pike (≤400 mm) were the primary consumers of juvenile Chinook and coho salmon in the Deshka River. A Fisher exact test indicated that prey length distributions differed (χ^2 = 96.7, df = 19, P < 0.001) between salmon and other fish prey found in northern pike stomachs (Figure 6a). All salmon prey were less than 15 cm in length, whereas 65% of other fish prey were greater than 15 cm in length. A second Fisher exact test further indicated that prey-predator length ratios also differed (χ^2 = 68.0, df = 6, P < 0.001) between salmon and other fish prey found in northern pike stomachs (Figure 6b). The lengths of salmon found in northern pike stomachs were mostly (i.e., 94%) less than 30% of the length of the predator that consumed them; whereas, the lengths of other fish found in northern pike stomachs were mostly (i.e., 88%) greater than 30% of the length of the predator that consumed them. An analysis of covariance indicated that regression slopes did not differ (P = 0.998) between lakes with and without salmon when prey fish lengths were regressed against the lengths of northern pike that consumed them (Figure 7). However, the regression intercepts were significantly greater (P < 0.001) in lakes without salmon compared to lakes with salmon. Our results were consistent with those of Scharf et al. (2000) who found that prey-predator size ratios were predominantly 10–20% but ranged to greater than 50% for some large-gape predators. Juanes (1994) found that as fish grow, successively larger preys were included in the diet due to their increased vulnerability, but smaller prey were never excluded from the diet because their relative vulnerability remained high. In contrast, our data indicate that larger fish prey were included in the diet more when smaller juvenile salmon were not available, which is consistent with the strong size-dependence of prey capture success rates (Juanes 1994).

AGE, SEX AND GROWTH

Northern pike ranged in age from 1 to 13 years in all study lakes. The median age of northern pike in Chelatna, Shell, and Whiskey lakes was 5 years (Table 9). Median age of northern pike in Redshirt Lake was 4 years, and in Trapper Lake median age was 3.5 years. Northern pike in Chelatna Lake exhibited a broader range of age classes (11); whereas, northern pike in Trapper Lake exhibited the smallest range (8) of age classes (Table 9). Chelatna Lake northern pike were predominantly 4- to 6-year-old fish, and they exhibited higher proportions of older fish (>7) than any other lake across all years (Table 9). The exception was 2011, when older fish were not as prevalent (Appendix A1). Northern pike in Shell Lake were predominantly age 3–6 for both sexes (Table 9). These age ranges were consistent for all years and either sex (2010–2012). Sexes were not completely determined in 2011 (Appendix A2). Ages mostly ranged from 5- to 7-years-old in Whiskey Lake, but there was also a high number of age-3 fish. In Redshirt Lake, most northern pike were 2- to 5-years-old, but ages 3 and 4 were frequently found in both sexes

(Appendix A3). The highest incident of a single age class among the 5 lakes was found at Trapper Lake (Table 9) where the dominant age was 3 years (38%). Two Fisher exact tests indicated that northern pike age compositions were significantly different ($\chi^2 = 234.1$, df = 44, $P < 0.001$) among lakes and significantly different ($\chi^2 = 66.0$, df = 11, $P < 0.001$) between lakes with and without salmon (Figure 8). Age compositions were skewed toward younger fish and lifespan appeared to be reduced in lakes without salmon.

Northern pike scales from Chelatna and Shell lakes exhibited more uniform and distinguishable circuli compared to scales from other the other lakes. These growth patterns were similar to those Laine (1991) described as clear growth zones. Pearse and Hansen (1992) studied northern pike scales from the Arctic-Yukon-Kuskokwim region of Alaska finding that scales were characterized by irregular growth, leading to difficulty in reading ages due to false annular checks and indistinct first year annulus. This later description better fits what was found at Whiskey, Trapper, and Redshirt lakes where northern pike densities were higher. Climatic conditions have probably affected the growth environment and availability of northern pike preferred prey, and these conditions are reflected in growth patterns and scale structure. Some difficulties associated with ageing northern pike are related to 1) older fish (10+ annuli), where scale growth rates diminish and annuli are crowded close together on the outer edges (Casselman 1979; Laine 1991); 2) distinguishing annuli and differences among lake samples (Pearse and Hansen 1992); and 3) interpreting plus growth on the outer edge. Other calcified structures such as cleithra may be considered in the future for corroborate age assessment.

Differences in northern pike sex ratios among lakes were related to the age composition of each population. Two chi-square tests indicated that relative numbers of male and female northern pike were significantly different ($\chi^2 = 9.9$, df = 4, $P = 0.042$) among lakes but not different ($\chi^2 = 0.07$, df = 1, $P = 0.070$) between lakes with and without salmon. Northern pike male-female sex ratios were close to 1.0 in Chelatna (0.92) and Whiskey (1.08) lakes and skewed toward more males in Redshirt (1.33), Trapper (1.45), and Shell (1.92) lakes (Table 10). Logistic regression analysis indicated that proportions of male northern pike in our study lakes were significantly correlated ($P = 0.006$) with fish age, but the lake ($P = 0.162$) and lake-by-age interaction ($P = 0.972$) terms in the model were not significant. The *c*-statistic was 0.615. Predicted male proportions generally declined with age (Figure 9) and were generally greater than 0.5 below age 6 and less than 0.5 above age 5. Casselman (1975) found more male than female northern pike were captured during spring because males were more active during spawning time and thus more susceptible to capture in all gears. However, in our study there was no systematic difference in sampling times that could account for differences in sex ratios among lakes (Tables 2–4).

In all study lakes, northern pike sampled ranged in length from 141 mm to 1,070 mm. Northern pike in Chelatna and Shell lakes exhibited the greatest length ranges, whereas those in Redshirt and Trapper lakes exhibited the narrowest length ranges (Table 1). Overall, mean lengths at Chelatna Lake were the largest at 574 mm and they ranged from 525 mm in 2011 to 634 mm in 2010 (Table 11). Shell Lake mean lengths ranged from 500 mm in 2010 to 518 mm in 2012 and an overall mean length of 510 mm (Table 12). In contrast, mean lengths from Whiskey, Redshirt and Trapper lakes were much smaller ranging from 355 mm at Redshirt Lake to 464 mm at Whiskey Lake (Table 13). Mean lengths of northern pike in Chelatna, Shell, and Whiskey lakes varied throughout the early, middle, and late sampling periods but there were no clear trends.

The von Bertalanffy growth model significantly fit the length-at-age data for male and female northern pike and both sexes pooled in all 5 of our study lakes (Table 14; Figure 10). The growth coefficient (K) was lower and the asymptotic length (L_∞) of the growth curve was greater for female than male northern pike in all lakes except Shell Lake (Table 14). The asymptotic length was also greater for male northern pike at Chelatna, Shell, and Whiskey lakes compared to Redshirt and Trapper lakes. Linear regression analyses indicated that growth parameters L_∞ and K were not correlated with mean northern pike gillnet CPUE, but the growth parameters w for female northern pike and both sexes pooled were significantly negatively correlated with mean northern pike gillnet CPUE (Table 15; Figure 11). Northern pike growth was also density dependent in 29 lakes studied in Minnesota and Wisconsin (Margenau 1995; Pierce et al. 2003). Diana (1987) concluded that northern pike growth was reduced due to competition for food resources, especially when preferred prey was unavailable or undersized. Invertebrates (mostly leeches, insects, and amphipods) were found in a higher proportion of the stomachs examined at Redshirt and Trapper lakes, which may explain the lower growth rates of these fish because growth rates are typically higher when mostly fish are consumed (Carpenter and Kitchell 1993).

CONCLUSIONS

Northern pike densities were generally higher in shallower lakes (i.e., Redshirt and Trapper) where juvenile salmon had been extirpated. In lakes with salmon, northern pike diets were dominated by other fish and salmon (73%); whereas, in lakes without salmon their diets were dominated by invertebrates (91%). In lakes without salmon, the lack of other fish in northern pike diets indicated that all fish had been largely extirpated from these lakes. Northern pike distributions were patchier in lakes with salmon and more uniform in lakes without salmon, possibly due to higher northern pike densities or more uniform invertebrate prey distributions in lakes without salmon. Most juvenile salmon were consumed by relatively small northern pike, and salmon preys were relatively small compared to the northern pike that consumed them. Northern pike less than 500 mm in length consumed 75% of the juvenile salmon. Ninety-four percent of salmon found in northern pike stomachs were less than 30% of the length of the predator that consumed them; whereas, 88% of other fish preys were greater than 30% of the length of the predator that consumed them. In lakes without salmon, age compositions were skewed toward younger fish and lifespan appeared to be reduced. Male proportions generally declined with age and were generally greater than 50% below age 6 and less than 50% above age 5 and these patterns did not differ among lakes. Northern pike growth rates were negatively density dependent, which was probably due in part to competition for food. But, growth rates were also reduced in lakes without salmon because northern pike consumed primarily lower quality invertebrate preys rather than fish.

Salmon probably continue to coexist with northern pike in relatively deep lakes due to habitat segregation which reduces predation on them. In these lakes, northern pike predation on salmon may be limited to short, temporal periods during salmon smolt migrations. Consequently, targeted gillnetting directed at removing northern pike near lake outlets in spring may reduce salmon predation losses.

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TABLES AND FIGURES

Table 1.–Total hours fished and number of northern pike captured in all gear types, mean northern pike hourly catch per unit effort (CPUE) in gillnets, and northern pike length range and sex ratio in 5 Susitna River drainage lakes, 2009–2012.

Lake	Total hours fished	Total northern pike catch	Mean gillnet CPUE	Length range (mm)	Males %	Females %	Ratio M/F
Chelatna	790.9	210	0.388	162–990	0.52	0.48	0.9:1
Redshirt	152.8	108	0.634	141–710	0.57	0.43	1.3:1
Shell	610.3	205	0.342	217–1070	0.66	0.34	1.9:1
Trapper	86.1	51	0.596	155–665	0.59	0.41	1.5:1
Whiskey	114.0	122	1.029	196–850	0.52	0.48	1.1:1

Table 2.–Northern pike catch per hour (CPUE) by gear and date in Chelatna Lake, 2010–2012.

Year	Period start date	Gear	Number of sets	Effort - hours fished	Number of northern pike	CPUE
2010	5/30	Gillnet	5	35.7	30	0.841
	5/30	Hoop net	1	23.5	0	0.000
	6/06	Gillnet	4	27.4	14	0.511
	6/06	Hook/line	1	1.0	4	4.000
	6/06	Hoop net	1	24.0	0	0.000
	6/21	Gillnet	4	22.6	5	0.221
	6/21	Hoop net	1	24.3	0	0.000
Totals & mean gillnet CPUE			17	158.4	53	0.524
2011	5/29	Gillnet	4	87.3	14	0.160
	5/29	Hook/line	4	6.3	13	2.080
	6/06	Gillnet	5	100.8	22	0.218
	6/06	Hook/line	1	1.5	12	8.000
	6/19	Gillnet	5	123.8	32	0.259
Totals & mean gillnet CPUE			19	319.6	93	0.212
2012	5/29	Gillnet	4	67.3	21	0.312
	5/29	Hook/line	1	0.5	1	2.000
	6/10	Gillnet	4	61.0	20	0.328
	6/18	Gillnet	8	184.1	22	0.119
Totals & mean gillnet CPUE			17	312.9	64	0.253

Table 3.–Northern pike catch per hour (CPUE) by gear and date in Shell Lake, 2010–2012.

Year	Period start date	Gear	Number of sets	Effort - hours fished	Number of northern pike	CPUE
2010	5/24	Gillnet	8	42.9	19	0.443
	6/05	Gillnet	5	47.3	18	0.380
	6/05	Hook/line	1	2.0	1	0.500
	6/17	Gillnet	2	50.0	18	0.360
Totals & mean gillnet CPUE			16	142.3	56	0.394
2011	5/18	Gillnet	1	13.3	5	0.377
	5/18	Smolt trap	1	1.0	1	1.000
	6/03	Gillnet	7	73.9	25	0.338
	6/14	Gillnet	11	132.2	28	0.212
	6/14	Hook/line	1	1.0	1	1.000
Totals & mean gillnet CPUE			21	221.3	60	0.309
2012	5/22	Gillnet	11	112.7	48	0.426
	6/04	Gillnet	11	112.6	27	0.240
	6/04	Hook/line	1	1.5	1	0.667
	6/17	Gillnet	2	20.0	13	0.650
Totals & mean gillnet CPUE			25	246.8	89	0.439

Table 4.–Northern pike catch per hour (CPUE) by gear and date in Redshirt, Trapper and Whiskey lakes, 2009–2012.

Lake	Period start date	Gear	Number of sets	Effort - hours fished	Number of northern pike	CPUE
Redshirt	8/17/09	Gillnet	2	36.3	21	0.579
	8/17/09	Hook/line	1	5.0	13	2.600
	5/24/11	Gillnet	9	111.6	74	0.663
Totals & mean gillnet CPUE			12	152.8	108	0.634
Trapper	5/26/11	Gillnet	9	86.1	51	0.596
Whiskey	5/18/12	Smolt trap	3	36.0	46	1.278
	5/18/12	Hook/line	2	3.0	12	4.000
	5/21/12	Gillnet	11	65.9	61	0.926
	5/21/12	Hook/line	2	7.4	13	1.752
	5/21/12	Smolt trap	4	48.0	8	0.167
	6/01/12	Gillnet	6	48.3	51	1.056
Totals & mean gillnet CPUE				208.6	191	1.029

Table 5.–Incidental catches of fish other than northern pike in 5 Susitna River drainage lakes, 2009–2012.

Lake	Year	Rainbow trout	Round whitefish[a]	Longnose sucker[a]	Grayling	Burbot	Lake trout	Kokanee	Humpback whitefish[a]
Chelatna	2010	1		6					
	2011		2	12	1				
	2012	8	16		2				
Shell	2010	1		17					
	2011			51		1	10		
	2012			6			1	1	
Redshirt	2009			3					
	2011			37					2
Trapper	2011			62					1
Whiskey	2012		1	1					

[a] Longnose sucker and whitefish were mature adults.

Table 6.–Frequency of occurrence (and percent) of prey items in northern pike stomachs in 5 Susitna River drainage lakes, 2009–2012.

		Chelatna		Shell		Redshirt		Trapper		Whiskey		Total	
Prey category	Taxonomic group	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Fish	Coho salmon	5	0.04	2	0.02	0	0.00	0	0.00	0	0.00	7	0.01
	Sockeye salmon	27	0.22	7	0.06	0	0.00	0	0.00	9	0.08	43	0.09
	Salmonids	40	0.33	10	0.08	0	0.00	0	0.00	9	0.08	59	0.12
	Whitefish	9	0.07	0	0.00	0	0.00	0	0.00	0	0.00	9	0.02
	Rainbow trout	6	0.05	1	0.01	0	0.00	0	0.00	0	0.00	7	0.01
	Northern pike	1	0.01	2	0.02	1	0.01	11	0.29	1	0.01	16	0.03
	Stickleback	0	0.00	34	0.28	0	0.00	0	0.00	71	0.61	71	0.14
	Other fish[a]	38	0.31	93	0.76	1	0.01	0	0.00	12	0.10	145	0.29
Invertebrates	Gammarid amphipods	0	0.00	0	0.00	62	0.66	0	0.00	0	0.00	63	0.13
	Insects	21	0.17	7	0.06	38	0.40	9	0.24	13	0.11	89	0.18
	Leeches	42	0.35	12	0.10	20	0.21	20	0.53	20	0.17	115	0.23
	Snails	3	0.02	0	0.00	0	0.00	0	0.00	0	0.00	3	0.01
Vertebrate	Red-backed voles	2	0.02	1	0.01	0	0.00	2	0.05	0	0.00	5	0.01
	Wood frog	5	0.04	0	0.00	0	0.00	0	0.00	0	0.00	5	0.01
	Birds	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
	Total non-empty	121	0.61	122	0.63	94	0.88	38	0.78	116	0.61	495	0.67
	Total empty	76	0.39	71	0.37	13	0.12	11	0.22	75	0.39	246	0.33
	Total	197		193		107		49		191		741	

Note: Percentages do not sum to 100%, because more than 1 prey item sometimes occurred in a single stomach.

[a] Other fish includes sculpins, longnose sucker and unidentifiable fish. In Shell and Whiskey lakes unidentifiable fish mass was permeated with stickleback spines.

Table 7.–Number and mean lengths (mm, SE in parentheses) of 8 taxonomic groups of prey fish found in northern pike stomachs in 5 Susitna River drainage lakes, 2009–2012.

	Chelatna		Shell		Redshirt		Trapper		Whiskey		Total	
Taxonomic group	Number	Length	Number	Length	Number	Length	Number	Length	Number	Length	Number	Length
Coho salmon	6	121 (18)	2	137 (37)	–	–	–	–	–	–	8	129 (11)
Sockeye salmon	81	46 (2)	7	123 (12)	–	–	–	–	13	67 (7)	101	52 (3)
Whitefish	9	–	–	–	–	–	–	–	–	–	9	–
Rainbow trout	6	232 (29)	1	125 (0)	–	–	–	–	–	–	7	205 (34)
Northern pike	1	–	2	333 (196)	1	200 (0)	11	206 (21)	1	–	16	226 (32)
Sucker	1	150 (0)	–	–	–	–	–	–	–	–	1	150 (0)
Sculpin	15	–	1	–	–	–	–	–	–	–	16	–
Other fish[a]	47	–	–	–	–	–	–	–	–	–	47	–
Total	166		13		1		11		14		205	

Table 8.–Number of salmonid prey segregated by northern pike length (mm) and sex in 5 Susitna River drainage lakes, 2009–2012.

	Male northern pike						Female northern pike					
Lake	*n*	Length	Coho	Sockeye	Whitefish	Rainbow tr.	*n*	Length	Coho	Sockeye	Whitefish	Rainbow tr.
Chelatna	0	200–299	–	–	–	–	1	200–299	0	0	2	0
	3	300–399	0	3	0	0	4	300–399	0	37	0	0
	5	400–499	3	16	0	0	5	400–499	0	8	1	0
	6	500–599	1	4	1	0	4	500–599	2	3	1	1
	5	600–699	1	3	2	0	3	600–699	0	1	2	0
	5	700–799	0	3	1	1	3	700–799	0	2	0	2
	0	800–899	–	–	–	–	2	800–899	0	0	0	2
Total	24		5	29	4	1	22		2	51	6	5
Shell	1	200–299	1	0	0	0	0	200–299	0	0	0	0
	0	300–399	–	–	–	–	0	300–399	–	–	–	–
	0	400–499	–	–	–	–	0	400–499	–	–	–	–
	4	500–599	1	3	0	0	0	500–599	–	–	–	–
	2	600–699	0	2	0	0	2	600–699	0	1	0	1
	0	700–799	–	–	–	–	1	700–799	0	1	0	0
	0	800–899	–	–	–	–	0	800–899	–	–	–	–
Total	7		2	5	0	0	3		0	2	0	1
Whiskey	3	200–299	0	7	0	0	1	200–299	0	1	0	0
	2	300–399	0	2	0	0	0	300–399	–	–	–	–
	1	400–499	0	1	0	0	1	400–499	0	1	0	0
	0	500–599	–	–	–	–	0	500–599	–	–	–	–
	0	600–699	–	–	–	–	1	600–699	0	1	0	0
	0	700–799	–	–	–	–	0	700–799	–	–	–	–
	0	800–899	–	–	–	–	0	800–899	–	–	–	–
Total	6		0	10	0	0	3		0	3	0	0

Table 9.–Mean length (mm) at age of northern pike captured in 5 Susitna River drainage lakes, 2009–2012.

	Chelatna			Shell			Whiskey			Redshirt			Trapper		
Age	*n*	Mean length	SE	*n*	Mean length	SE	*n*	Mean length	SE	*n*	Mean length	SE	*n*	Mean length	SE
1	1	168	–	0	–	–	0	–	–	2	159	2	4	170	9
2	10	248	26	4	340	17	1	234	–	12	230	16	2	235	41
3	13	371	17	30	369	9	17	303	9	28	318	8	18	311	4
4	24	494	11	45	477	7	10	375	10	27	359	10	3	400	37
5	28	517	12	53	561	6	32	454	5	12	424	17	5	490	21
6	21	592	13	24	613	10	25	510	10	6	488	26	9	547	12
7	6	662	17	5	681	16	19	592	8	1	497	–	3	557	22
8	15	712	12	2	738	28	3	616	48	1	584	–	4	568	34
9	12	762	13	1	853	–	2	731	3	2	691	20	0	–	–
10	9	808	17	0	–	–	1	730	–	0	–	–	0	–	–
11	11	827	23	0	–	–	0	–	–	0	–	–	0	–	–
12	0	–	–	0	–	–	0	–	–	0	–	–	0	–	–
13	0	–	–	1	1070	–	0	–	–	0	–	–	0	–	–
Overall mean length		576	14		516	9		470	11		353	11		401	20
Median age		5.0			5.0			5.0			4.0			3.5	
Age range		1–11			2–13			2–10			1–9			1–8	

Table 10.–Age composition and sex ratios of northern pike in 5 Susitna River drainage lakes, 2009–2012.

	Chelatna			Shell			Whiskey			Redshirt			Trapper		
Age	%	%M	%F	%	%M	%F	%	%M	%F	%	%M	%F	%	%M	%F
1	1	0	0	0	0	0	0	0	0	2	2	0	8	6	2
2	7	2	1	2	1	3	1	0	1	13	10	3	4	4	0
3	9	4	4	18	12	4	16	13	3	31	17	14	38	25	13
4	16	11	6	27	10	13	9	6	3	30	18	12	6	6	0
5	19	12	8	32	16	17	29	21	8	13	4	9	10	4	6
6	14	5	10	15	10	9	23	13	10	7	4	2	19	6	13
7	4	1	3	3	3	2	17	6	12	1	1	0	6	2	4
8	10	6	5	1	1	0	3	1	2	1	0	1	8	4	4
9	8	3	6	1	0	0	2	1	1	2	0	2	0	0	0
10	6	2	4	0	0	0	1	0	1	0	0	0	0	0	0
11	7	4	4	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Totals		47.9	52.1		65.8	34.2		51.8	48.2		57.0	43.0		59.2	40.8
Male-Female ratio		0.92			1.92			1.08			1.33			1.45	

Note: Percent columns include all aged fish, and Percent Male and Percent Female columns only include fish which were both aged and sexed. Male–Female Ratios were determined from all sexed fish.

Table 11.–Mean lengths (mm) of northern pike captured in Chelatna Lake by date, 2010–2012.

Year	Period start date	*n*	Mean length	SE	Minimum length	Median length	Maximum length
2010	5/30	30	604	23.1	308	581	835
	6/06	18	672	35.0	452	695	990
	6/21	5	675	70.6	426	669	831
Total		53	634	19.1			
2011	5/29	22	540	23.0	382	505	760
	6/06	28	534	26.2	212	514	810
	6/19	30	507	26.4	265	490	900
Total		80	525	14.8			
2012	5/29	22	602	36.9	162	611	825
	6/10	20	669	32.0	285	707	860
	6/18	22	494	45.9	168	512	860
Total		64	586	24.0			
Overall		197	574	11.5			

Table 12.–Mean lengths (mm) of northern pike captured in Shell Lake by date, 2010–2012.

Year	Period start date	*n*	Mean length	SE	Minimum length	Median length	Maximum length
2010	5/24	19	564	29.5	240	592	724
	6/05	16	506	27.6	355	501	723
	6/17	18	428	31.6	217	427	730
Total		53	500	18.7			
2011	5/18	6	538	35.3	470	505	700
	6/03	25	522	28.2	305	510	1070
	6/14	24	482	12.3	295	498	570
Total		55	506	14.5			
2012	5/22	48	533	15.2	306	548	853
	6/04	25	485	25.9	300	493	766
	6/17	12	525	35.8	359	530	687
Total		85	518	12.6			
Overall		193	510	8.6			

Table 13.–Mean lengths (mm) of northern pike captured in Redshirt, Trapper and Whiskey lakes by date, 2009–2012.

Lake	Year	Period start date	*n*	Mean length	SE	Minimum length	Median length	Maximum length
Redshirt	2009	8/17	34	327	12.7	158	326	497
	2011	5/24	74	368	13.1	141	350	710
	Overall		108	355	10.0			
Trapper	2011	5/26	49	406	19.9	155	342	665
Whiskey	2012	5/18	58	445	16.6	196	476	670
		5/21	82	480	13.7	234	479	850
		6/01	51	462	13.9	273	449	730
	Overall		191	464	8.6			

Table 14.–Von Bertalanffy growth model parameters estimated for male and female northern pike and both sexes pooled in 5 Susitna River drainage lakes, 2009–2012.

		L_∞		K				
Lake	Sex	Point	SE	Point	SE	*w*	*n*	*P*-value
Chelatna	Male	931	39	0.176	0.014	163.9	72	<0.001
	Female	1099	72	0.134	0.015	147.3	72	<0.001
Redshirt	Male	523	54	0.294	0.055	153.8	51	<0.001
	Female	1006	141	0.121	0.023	121.7	46	<0.001
Shell	Male	1176	91	0.123	0.014	144.6	106	<0.001
	Female	1110	164	0.142	0.030	157.6	55	<0.001
Trapper	Male	677	58	0.219	0.032	148.3	28	<0.001
	Female	909	122	0.149	0.032	135.4	20	<0.001
Whiskey	Male	984	128	0.122	0.022	120.0	66	<0.001
	Female	1342	176	0.084	0.014	112.7	44	<0.001
Chelatna	Pooled	1031	40	0.148	0.010	152.6	151	<0.001
Redshirt	Pooled	830	94	0.151	0.024	125.3	92	<0.001
Shell	Pooled	1212	82	0.123	0.011	149.1	166	<0.001
Trapper	Pooled	796	62	0.177	0.022	140.9	48	<0.001
Whiskey	Pooled	1229	130	0.092	0.013	113.1	110	<0.001

Table 15.–Results from 9 linear regression analyses conducted using L_∞, K, and *w* as dependent variables and mean northern pike gillnet CPUE in each lake as independent variables.

Sex	Parameter	R^2	*P*	Intercept (SE)	Slope (SE)
Male	L_∞	0.091	0.662	1084 (298)	-264 (482)
	K	0.001	0.99	0.169 (0.085)	0.002 (0.137)
	w	0.593	0.128	170 (13)	-44 (21)
Female	L_∞	0.362	0.283	943 (142)	301 (231)
	K	0.845	0.027	0.169 (0.012)	-0.079 (0.019)
	w	0.867	0.022	173 (9)	-63 (14)
Both	L_∞	0.007	0.894	1040 (226)	53.57 (369)
	K	0.285	0.354	0.162 (0.029)	-0.052 (0.048)
	w	0.913	0.011	171 (6)	-58 (10)

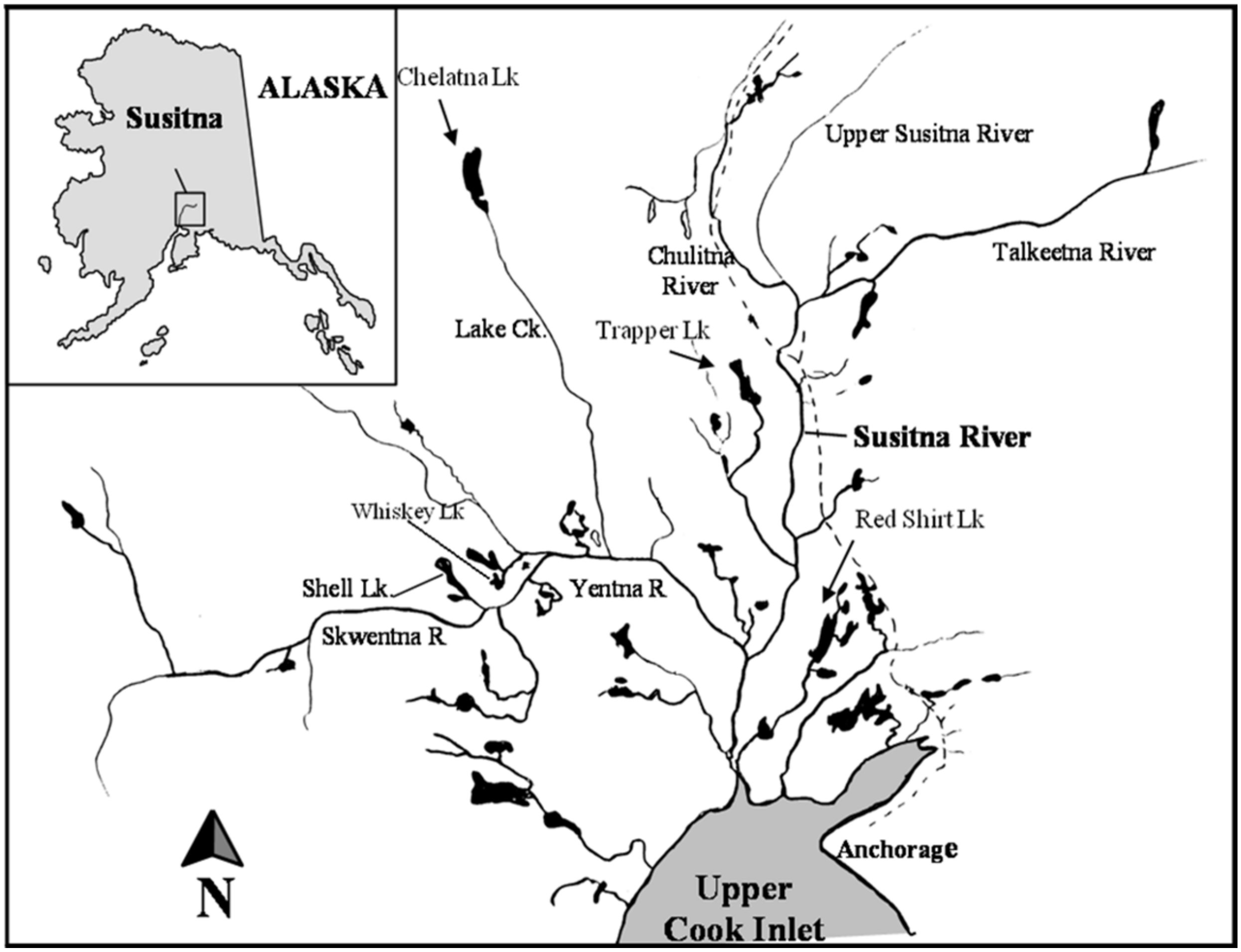

Figure 1.–Susitna River watershed and 5 sockeye salmon rearing lakes included in this study.

a.

b.

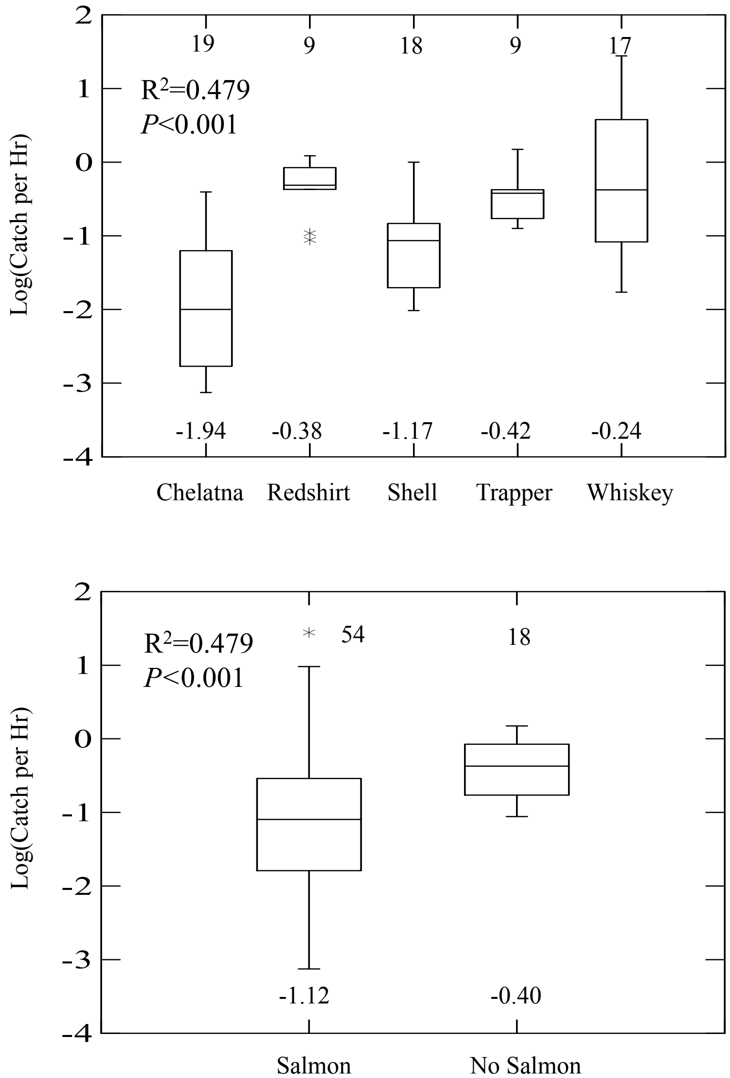

Figure 2.–Box plots indicating the distributions of northern pike catch per hour (natural-logarithm transformed) in gillnets fished in (a) 5 Susitna River drainage lakes, and (b) in the same lakes grouped by whether salmon were present (Chelatna, Shell and Whiskey lakes) or not present (Redshirt and Trapper lakes).

Note: The number of net sets made in each lake (or group of lakes) is indicated along the top of each panel, the least-squares mean catch per hour (natural-logarithm transformed) is indicated along the bottom of each panel, and *P*-values indicate results from analyses of variance.

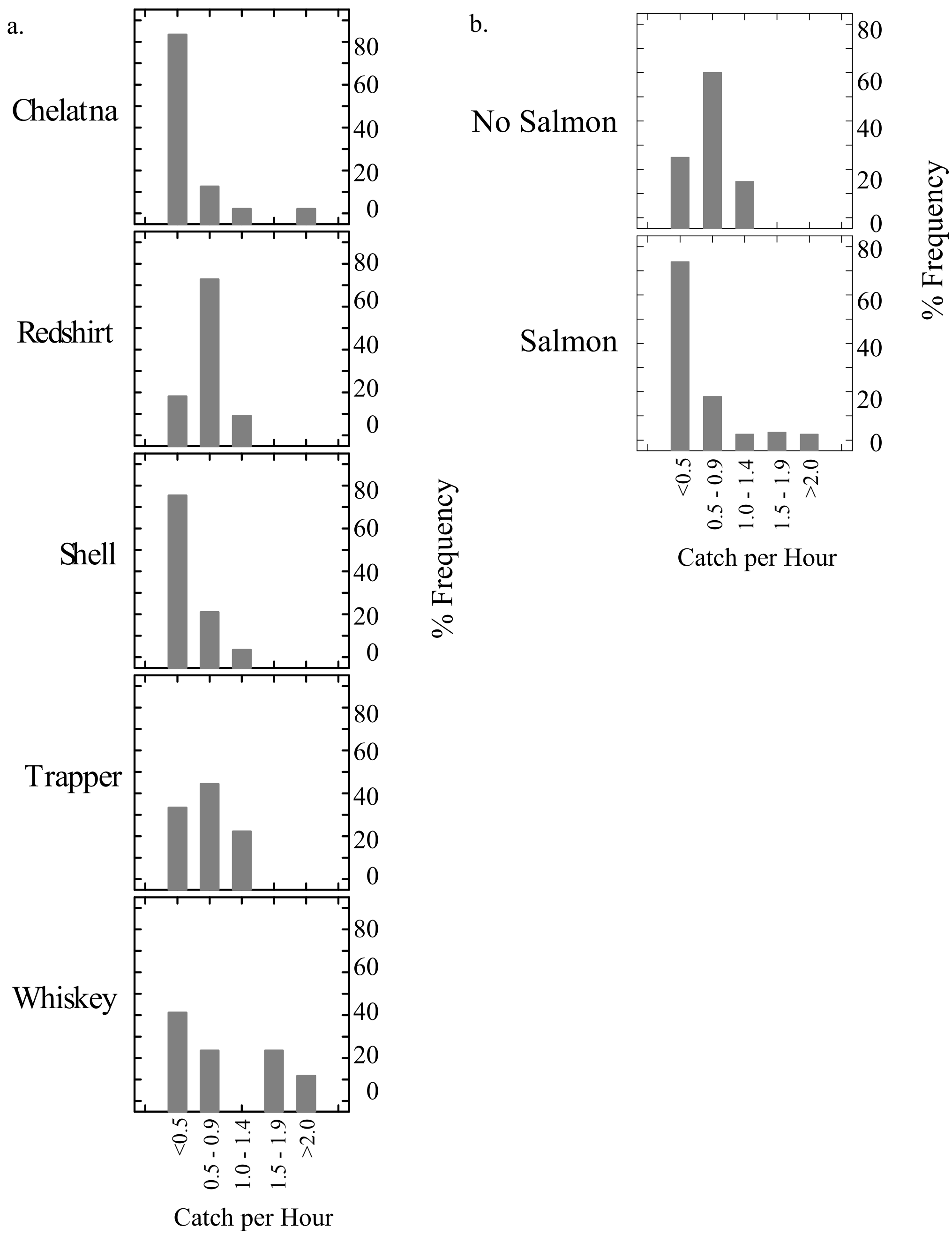

Figure 3.–Percent frequency of occurrence of northern pike catch per hour in gillnets fished in (a) 5 Susitna River drainage lakes, and (b) in the same lakes grouped by whether salmon were present (Chelatna, Shell and Whiskey lakes) or not present (Redshirt and Trapper lakes).

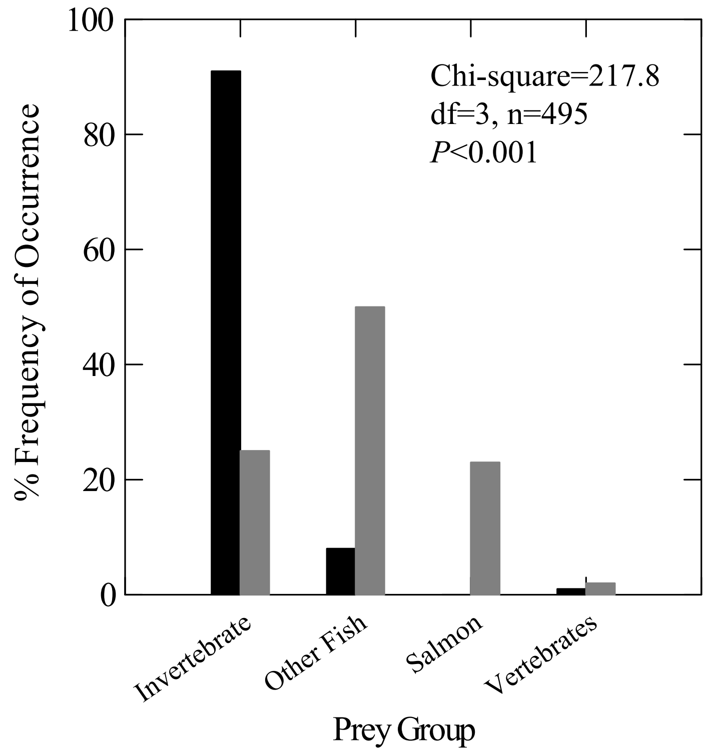

Figure 4.–Percent frequency of occurrence of 4 prey groups in stomachs of northern pike sampled in lakes with salmon (grey bars) and without salmon (black bars).

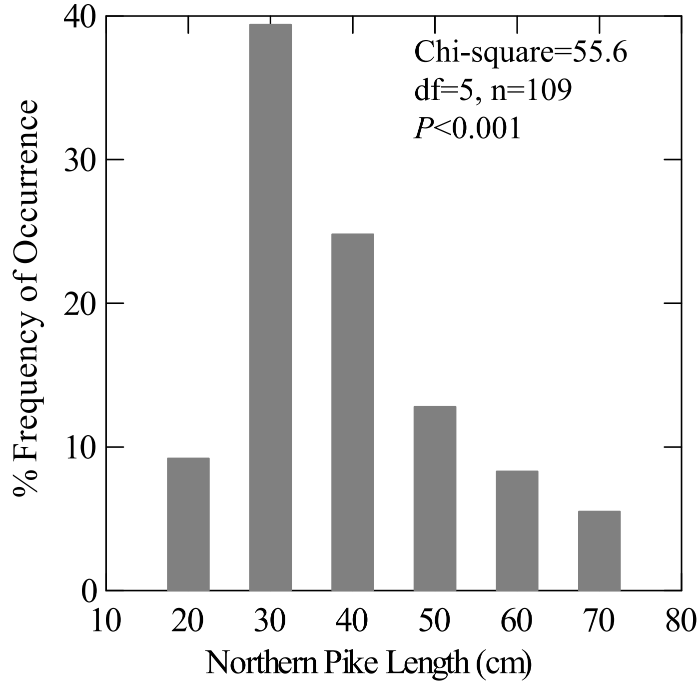

Figure 5.–Results from a chi-square analysis that tested whether the number of juvenile salmon found in northern pike stomachs differed among six 10-cm northern pike length classes.

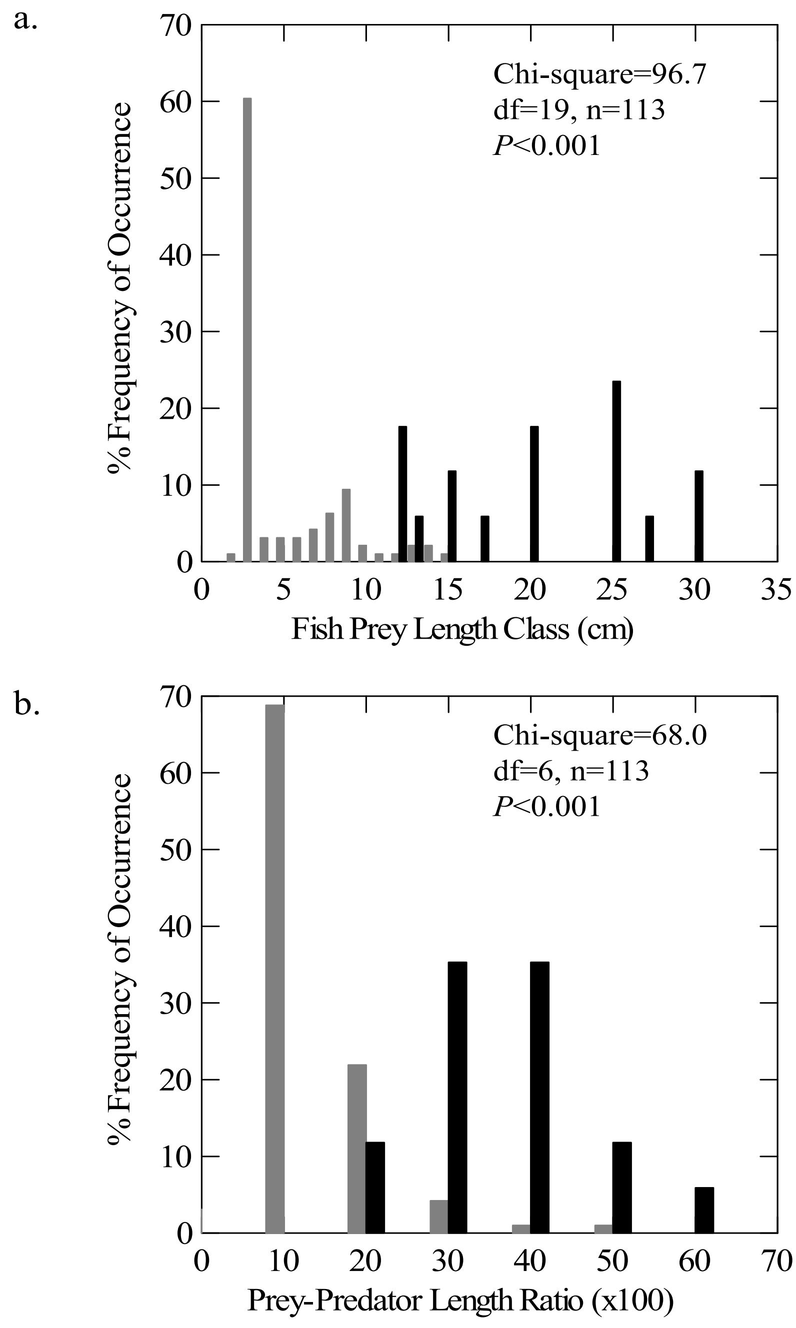

Figure 6.–Results from 2 chi-square analyses that tested whether (a) prey length distributions differed between salmon (gray bars) versus non-salmon (black bars) prey, and (b) whether prey-predator length ratios differed between salmon (gray bars) versus non-salmon (black bars) prey.

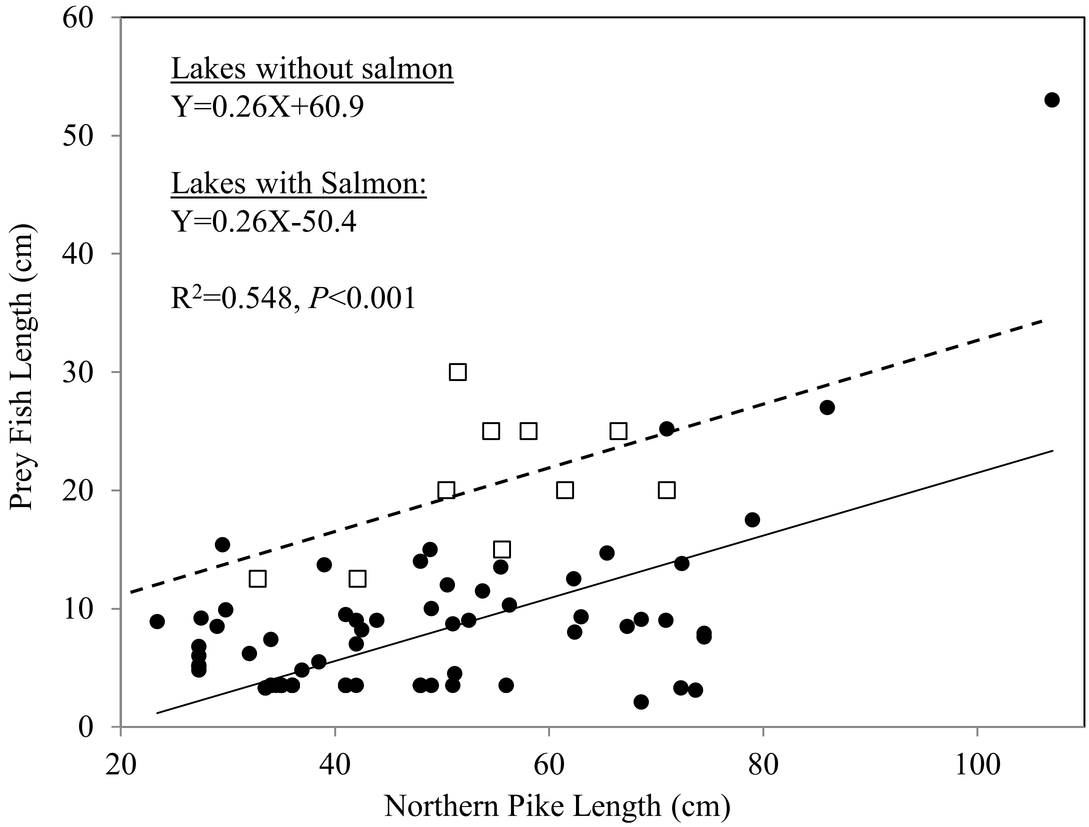

Figure 7.–Results from an analysis of covariance that tested whether the relationship between prey fish lengths and lengths of northern pike that consumed them differed between lakes with salmon (solid circles and solid line) and without salmon (open squares and dashed line).

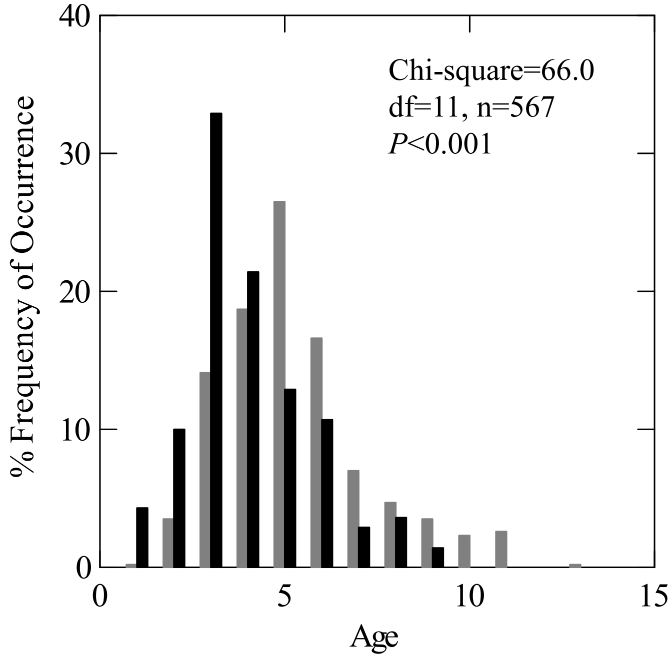

Figure 8.–Age composition of northern pike in lakes with salmon (grey bars) and lakes without salmon (black bars).

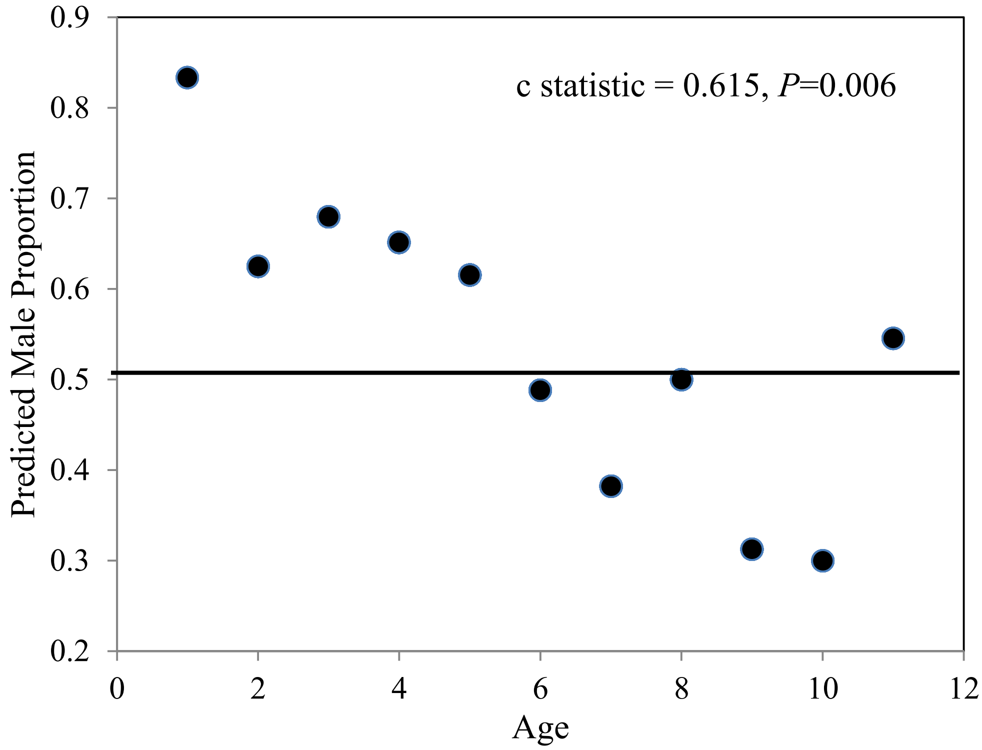

Figure 9.–Proportions of male northern pike in relation to fish age predicted from a logistic regression model.

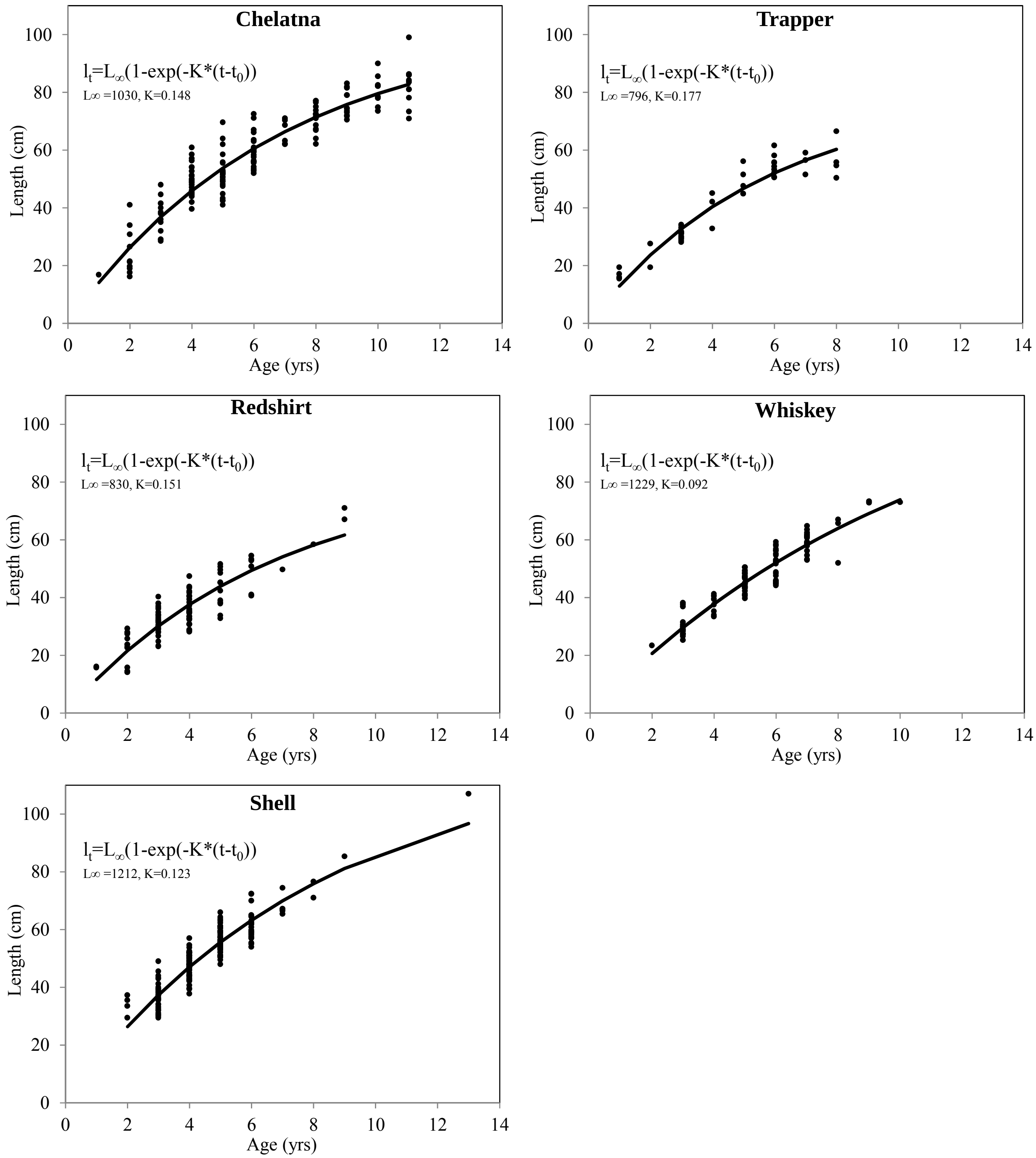

Figure 10.–Von Bertalanffy growth model fit to northern pike length-at-age data (both sexes pooled) from 5 Susitna River drainage lakes.

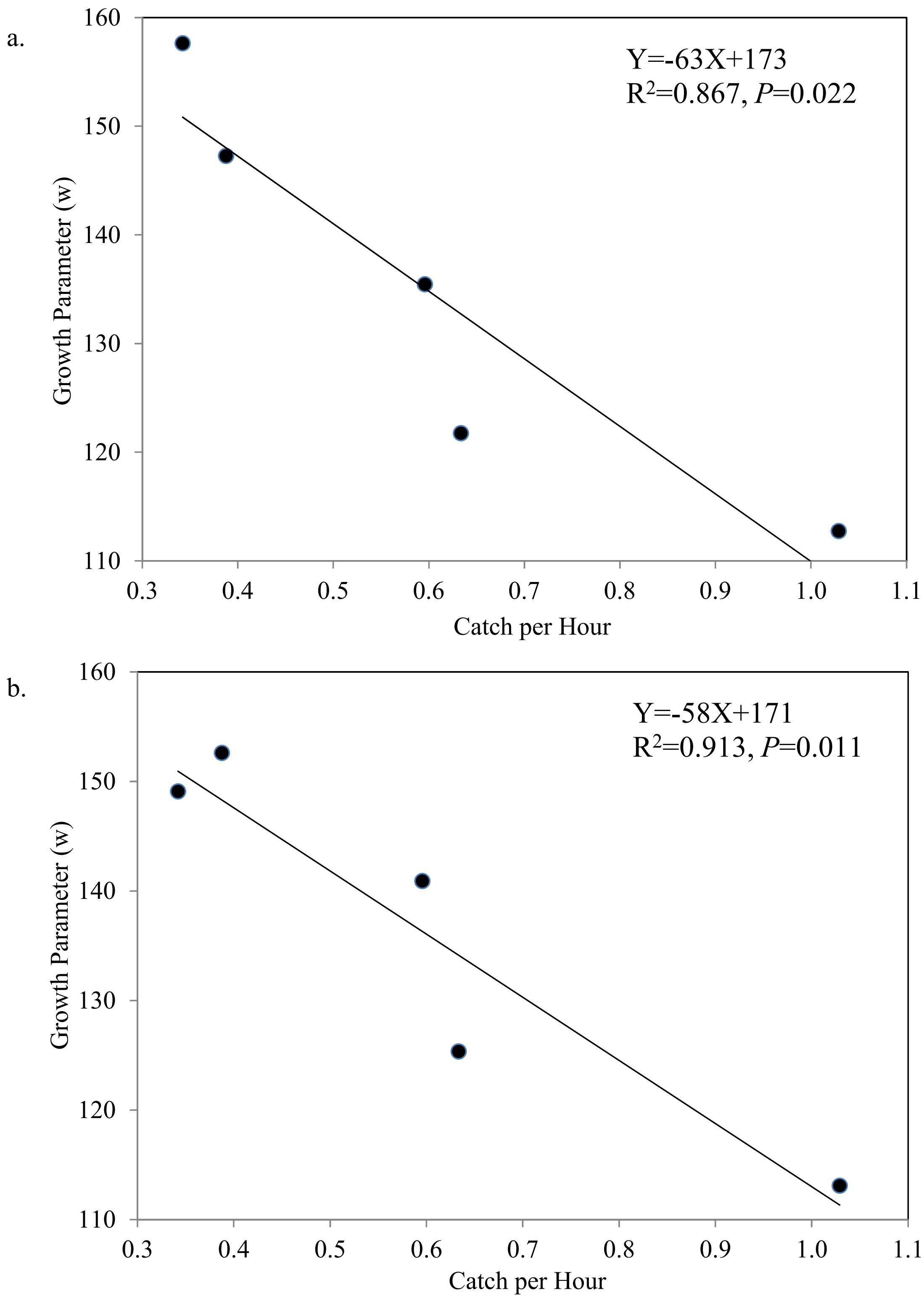

Figure 11.–Relationships between the von Bertalanffy growth parameter (w, i.e. L_∞ x K) and mean northern pike gillnet catch per hour in 5 Susitna River drainage lakes for (a) female northern pike and (b) both sexes pooled.

APPENDIX A: NORTHERN PIKE AGE COMPOSITION

Appendix A1.–Chelatna Lake northern pike, sex and estimated age proportions by year, 2010–2012.

	Age											
2010	1	2	3	4	5	6	7	8	9	10	11	Total
Females												
Number sampled	0	0	0	3	1	1	0	2	4	1	2	14
Proportion	0.00	0.00	0.00	0.07	0.02	0.02	0.00	0.05	0.09	0.02	0.05	0.33
Mean length				586	696	661		744	769	822	913	
SE mean length				13				28	22		78	
Males												
Number sampled	0	1	2	6	10	2	2	3	2	0	1	29
Proportion	0.00	0.02	0.05	0.14	0.23	0.05	0.05	0.07	0.05	0.00	0.02	0.67
Mean length		308	431	493	552	593	695	689	774		863	
SE mean length			16	19	15	17	9	18	57			
Combined												
Number sampled	0	1	2	9	11	3	2	5	6	1	3	43
Proportion	0.00	0.02	0.05	0.21	0.26	0.07	0.05	0.12	0.14	0.02	0.07	
Mean length		308	431	524	565	615	695	711	770	822	896	
SE mean length			16	20	19	25	9	19	20		48	
2011												
Females												
Number sampled	0	2	5	5	4	6	1	3	1	1	0	28
Proportion	0.00	0.04	0.10	0.10	0.08	0.13	0.02	0.06	0.02	0.02	0.00	0.58
Mean length		303	401	471	491	604	710	725	815	900		
SE mean length		38	23	21	24	30		43				
Males												
Number sampled	0	2	3	9	3	1	0	2	0	0	0	20
Proportion	0.00	0.04	0.06	0.19	0.06	0.02	0.00	0.04	0.00	0.00	0.00	0.42
Mean length		311	362	480	495	635		724				
SE mean length		99	21	15	44			1				
Combined												
Number sampled	0	4	8	14	7	7	1	5	1	1	0	48
Proportion	0.00	0.08	0.17	0.29	0.15	0.15	0.02	0.10	0.02	0.02	0.00	
Mean length		307	386	477	493	608	710	725	815	900		
SE mean length		43	17	12	21	26		23				

-continued-

Appendix A1.–Page 2 of 2.

2012	Age 1	2	3	4	5	6	7	8	9	10	11	Total
Females												
Number sampled	0	0	1	1	6	7	3	2	3	4	3	30
Proportion[a]	0.00	0.00	0.02	0.02	0.12	0.13	0.06	0.04	0.06	0.08	0.06	0.58
Mean length			285	460	484	573	625	666	742	803	854	
SE mean length					16	13	4	45	25	23	6	
Males												
Number sampled	0	0	1	0	4	4	0	3	2	3	5	22
Proportion[a]	0.00	0.00	0.02	0.00	0.08	0.08	0.00	0.06	0.04	0.06	0.10	0.42
Mean length			291		474	580		724	739	779	769	
SE mean length					15	18		20	4	25	21	
Combined												
Number sampled[b]	1	5	3	1	10	11	3	5	5	7	8	59
Proportion	0.02	0.08	0.05	0.02	0.17	0.19	0.05	0.08	0.08	0.12	0.14	
Mean length	168	188	289	460	480	576	625	701	741	793	801	
SE mean length		9	2		11	10	4	23	14	16	20	

[a] Proportion includes only fish which were sexed.

[b] Sex of 7 small fish could not be determined in the field.

Appendix A2.–Shell Lake northern pike, sex and estimated age proportions by year, 2010–2012.

	Age									
2010	2	3	4	5	6	7	8	9	13	Total
Females										
Number sampled	3	1	3	4	4	0	0	0	0	15
Proportion	0.08	0.03	0.08	0.10	0.10	0.00	0.00	0.00	0.00	0.38
Mean length	334	385	529	598	665					
SE mean length	23		9	21	34					
Males										
Number sampled	1	5	5	6	4	2	1	0	0	24
Proportion	0.03	0.13	0.13	0.15	0.10	0.05	0.03	0.00	0.00	0.62
Mean length	355	392	455	564	616	662	710			
SE mean length		23	22	23	26	8				
Combined										
Number sampled	4	6	8	10	8	2	1	0	0	39
Proportion	0.10	0.15	0.21	0.26	0.21	0.05	0.03	0.00	0.00	
Mean length	340	391	482	578	640	662	710			
SE mean length	17	19	19	16	22	8				
2011										
Sexes combined										
Number sampled		9	19	16	3	0	0	0	1	48
Proportion	0.00	0.19	0.40	0.33	0.06	0.00	0.00	0.00	0.02	
Mean length		396	488	539	640				1070	
SE mean length		20	8	11	38					
2012										
Females										
Number sampled	0	4	12	15	6	2	0	0	0	39
Proportion[a]	0.00	0.05	0.16	0.20	0.08	0.03	0.00	0.00	0.00	0.53
Mean length		347	460	563	597	708				
SE mean length		12	14	8	11	36				
Males										
Number sampled	0	9	6	12	7	1	0	0	0	35
Proportion[a]	0.00	0.12	0.08	0.16	0.09	0.01	0.00	0.00	0.00	0.47
Mean length		350	470	571	584	665				
SE mean length		11	18	10	8					
Combined										
Number sampled[b]	0	15	18	27	13	3	1	1	0	78
Proportion	0.00	0.19	0.23	0.35	0.17	0.04	0.01	0.01	0.00	
Mean length		344	463	567	590	694	766	853		
SE mean length		8	11	6	7	25				

[a] Proportion includes only fish which were sexed.

[b] Sex of 4 fish could not be determined in the field.

Appendix A3.–Redshirt Lake northern pike, sex and estimated age proportions, 2009, 2011.

	Age									
2009	1	2	3	4	5	6	7	8	9	Total
Females										
Number sampled	0	2	2	6	1	0	0	0	0	11
Proportion	0.00	0.07	0.07	0.21	0.03	0.00	0.00	0.00	0.00	0.38
Mean length		227	278	353	383					
SE mean length		1	45	18						
Males										
Number sampled	0	2	4	7	3	1	1	0	0	18
Proportion	0.00	0.07	0.14	0.24	0.10	0.03	0.03	0.00	0.00	0.62
Mean length		198	269	320	352	406	497			
SE mean length		40	17	9	19					
Combined										
Number sampled	0	4	6	13	4	1	1	0	0	29
Proportion	0.00	0.14	0.21	0.45	0.14	0.03	0.03	0.00	0.00	
Mean length		212	272	336	360	406	497			
SE mean length		18	16	10	16					

2011										
Females										
Number sampled	0	1	11	5	7	2	0	1	2	29
Proportion	0.00	0.02	0.18	0.08	0.11	0.03	0.00	0.02	0.03	0.47
Mean length		141	331	400	460	531		584	691	
SE mean length			8.5	26	16	3			20	
Males										
Number sampled	2	7	11	9	1	3	0	0	0	33
Proportion	0.03	0.11	0.18	0.15	0.02	0.05	0.00	0.00	0.00	0.53
Mean length	159	252	330	369	424	488				
SE mean length	2	19.1	13	17		40				
Combined										
Number sampled	2	8	22	14	8	5	0	1	2	62
Proportion	0.03	0.13	0.35	0.23	0.13	0.08	0.00	0.02	0.03	
Mean length	159	238	331	380	456	505		584	691	
SE mean length	2	22	8	14	15	24			19.5	